

Chapter 5: Summary of Program Elements and Resource Requirements

Table 5.1 breaks out the Carbon Cycle Science Plan (CCSP) program elements and summarizes the research components and approximate costs. The elements are also mapped onto the CCSP goals as described below.

Initial Funding Priorities

Most of the program elements outlined below serve more than one of the major long-term and five-year goals. Again, the program requires a coordinated, integrated approach by the responsible agencies: the value of an integrated program will greatly exceed the return from uncoordinated program elements.

The individual program elements described in this plan, however, are not at equal stages of readiness. Some program elements represent work that has been constrained by limited resources in the past and could begin immediately with a near-term infusion of funding. New technology enterprises, for example, have suffered disproportionately in the recent past due to such resource constraints. Since many of the program elements in the CCSP call for focused technology development prior to large-scale implementation, we recommend that a high priority be placed on funding those technology development efforts that have been deferred due to insufficient funding. More specifically, the following program elements should be considered as high priorities for initial funding:

- Both facility and technology development for the enhanced flux network, airborne sampling, and automated and streamlined ocean sampling for long time-series and underway measurements
- Airborne CO₂ monitoring programs, both dispersed weekly measurements and in support of regional studies
- An expanded and enhanced surface monitoring network for atmospheric CO₂
- Improved forest inventories (with carbon measurements a key focus and an explicit goal) and development of new techniques for remote sensing of above-ground biomass
- Analysis of World Ocean Circulation Experiment/Joint Global Ocean Flux Study (WOCE/JGOFS) data for CO₂ uptake by the oceans
- New ongoing program of air-sea carbon flux and ocean inventory measurements

- Continued ocean process studies and enhanced manipulation experiments
- Enhanced development of Earth system modeling to include interactive carbon and climate dynamics.

Mapping of Program Elements to CCSP Goals

The following paragraphs map the program elements shown in Table 5.1 to the goals and objectives of the Carbon Cycle Science Plan.

Goal 1: Program Elements 1-4, 6-9, 11

The program elements (1) expanded terrestrial flux network, (2) airborne CO₂ observation program, (3) global CO₂ monitoring network, and (4) land use inventories, taken together, address the first part of the CCSP Goal 1: to quantify the Northern Hemisphere terrestrial sink and more generally, to quantify the global terrestrial sink for CO₂. Program elements (1), (2), and (3) together provide direct long-term measurements defining sources and sinks on regional scales. The proposed airborne observations (2) are capable of providing integrated measures of regional net exchange several times per month; the conceptual framework for interpreting these observations needs to be strengthened and tested through a series of strategically planned regional observation experiments (6). The expanded flux network (1) complements the other elements by determining monthly and annually averaged regional net uptake or release in typical ecosystems. The flux network will be able to define the systematic differences between flight days and non-flight days for the airborne profile measurements. Flux data can help account for CO₂ net exchange on days when analysis of the regional net exchange is not possible from atmospheric data, e.g., during frontal passages or large weather events.

Improved carbon and land use inventories (4) provide a first-order check on the inferences from atmospheric measurements. By telling us where the carbon is going (or coming from), program element 4 also contributes significantly to the second part of Goal 1, to understand the underlying mechanisms that regulate the Northern Hemisphere terrestrial sink, and more generally, global terrestrial sinks and sources. The long-term terrestrial observations (7), process studies and manipulations (8) provide

Program Elements and Resource Requirements*

The following table breaks out the program elements and summarizes the research components and approximate costs. In Chapter 5, these elements are mapped onto the program goals that were outlined above. Both program goals and program elements are discussed in greater detail in Chapter 4 and Chapter 6.

Project Element	Deliverable	Description	Development/Start-up	Operations Cost
1. Expanded Flux Network†	Net CO ₂ exchange across major biophysical gradients	100-150 eddy flux network sites, operated long-term	Technology dev., (\$5M) and initial installation, (\$15M) over 5 yrs	\$20M/yr
2. Airborne CO ₂ Observation Program†	Three-dimensional and temporal distributions of CO ₂ and tracers over North America, analyzed to define regional sources/sinks, and constrain atmospheric transport models	Newly developed weekly monitoring network at 50 distributed North American sites deployed on general aviation aircraft with a combination of flask and on-board continuous sampling units; development and operation supported by periodic intensive field measurements (element 6 below)	\$10M	\$10M/yr
3. Global CO ₂ Monitoring Network	Enhanced space/time data for CO ₂ and tracers, defining regional sources/sinks on a global scale, and constraining atmospheric transport models	Increased number (by a factor of 3) of flask and continuous monitoring stations measuring CO ₂ and tracers, emphasizing continental and remote marine locations; vertical profiles at selected locations as specified in element 2.		\$10M/yr
4. Global Terrestrial Carbon and Land Use Inventories	Vegetation cover, above- and below-ground carbon, and rates of change; input data, constraints, and representation of mechanisms in biogeochemical models	(a) Expanded and reformed Forest Inventory Analysis program to include carbon as a focus, with shorter return intervals, more ecological measurements and greater transparency and traceability (b) New satellite observations (nested high-resolution and LANDSAT imagery, new radar mapping) (c) Analysis of current soil carbon inventories and expansion to monitor eroded carbon and other effects of land use on soil carbon	(a) \$10M/yr (b) \$10-30M/yr for 5 yr (c) \$5M	(a) \$10M/yr (b) \$10M/yr (c) \$5M/yr
5. Reconstruction of Historical CO ₂ Emissions	Estimates of historical sources and sinks due to human land use, to be used to constrain predictive models.	Analysis of existing data, synthesis into data sets available for carbon modeling, and development of new historical carbon-cycle models; significant role for remote sensing (LANDSAT 7, MODIS)	\$2M	\$2M/yr
6. Regional Observational Experiments	Direct regional determinations of fluxes and concentrations of CO ₂ , greenhouse gases, pollutants	Coordinated airborne, ship, terrestrial, and satellite experiments integrated with model development and testing (e.g. BOREAS)		\$5-10M/yr
7. Long-Term Terrestrial Observations	Long-term vegetation, soil, and flux data for major biomes, new emphasis on disturbed and managed sites	30-40 long-term regional sites to evaluate natural disturbance and management effects on carbon fluxes (e.g. increasing focus on carbon, and greater number and types of sites in the NSF LTER network)		\$40M/yr
8. Terrestrial Process Studies and Manipulations	Long-term, large-scale effects on the biosphere and on carbon sequestration of predicted environmental changes not occurring in nature today	20-30 major, long-term experiments at ecosystem scale manipulating CO ₂ , nutrients, water, ozone, temperature, etc.	\$20-30M	\$20-30M/yr
9. Global Ocean Measurements (surveys, time series, remote sensing)	Ocean/atmosphere fluxes; basin-scale net uptake of anthropogenic CO ₂ at reduced cost, and interpretation of seasonal variances, atmosphere-ocean-biology interactions.	(a) Complete analysis of recent global survey data (b) Develop and deploy time-series and drifting buoys and automated towed vertical samplers for CO ₂ , and related parameters (DIC, DOM, POM, alkalinity, O ₂ , nutrients, ¹³ CO ₂ , ¹⁴ CO ₂ , T, S) and tracers of ocean circulation (CFCs, ¹⁴ C, ³ H/ ³ He), reduce cost per measurement, increase data flow	\$25M	\$30-50M/yr
10. Ocean Process Studies and Manipulations	Define effects of biology, circulation, atmospheric deposition, and river fluxes on the distribution of oceanic carbon, and rates of invasion/release of industrial CO ₂	(a) Physical and biological studies of dispersion of anthropogenic CO ₂ and controls on new production/uptake (b) Ocean manipulation experiments (~2-yr duration) to examine hypotheses such as the role of iron in ecosystem production		(a) \$10M/yr (b) \$10M/yr
11. Modeling and Synthesis	Develop and apply models for analysis of data, synthesis, prediction, policy	Improved ocean, atmosphere and land simulations, rigorous, independent, comparisons of models with data. Develop Earth System models that predict CO ₂ and climate interactively		\$15-30M/yr
TOTALS	Present new knowledge, meet societal needs, devise cost-effective approaches	(Note: estimated current annual spending for carbon-focused work in FY1998 was \$40-50M)	\$135-300M over 5 years	\$200-250M/yr

*For explanation of acronyms, see the acronym list at the end of this report.

†Technology development will be a critical focus in the initial phase of this activity.

fundamental tools to develop new understanding of terrestrial sinks and sources.

Estimates of the Northern Hemisphere terrestrial carbon sink made from atmospheric CO₂ observations are very sensitive to the magnitude of the carbon sink in the North Atlantic and North Pacific. Oceanic observations (10) in the North Atlantic and Pacific Oceans thus provide important constraints on the Northern Hemisphere terrestrial carbon sink.

Modeling and synthesis (11) provide a large-scale check on inferred Northern and global fluxes when combined with global network (3) and airborne (2) data, and allow tests of our understanding through simulations of past and present conditions.

Goal 2: Program Elements 2, 3, 6, 9-11

The elements (9) surveys, time series, remote sensing, (10) a quantitative understanding of air-sea exchange processes, (2) airborne CO₂ observation program, and (3) global CO₂ monitoring network together address the first part of Goal 2: to quantify the oceanic uptake of CO₂; global ocean measurements. These elements provide direct long-term measurements defining sources and sinks on the scale of major ocean regions. A critically important task is to successfully integrate expanded observations of time series at key locations, observations of atmosphere-ocean exchange, periodic global ocean surveys, remote sensing of the oceans, large-scale airborne measurements over the oceans, and atmospheric data from island stations. The conceptual framework for interpreting these observations will be developed and tested in element (6), strategically planned regional observation experiments.

Ocean process studies and manipulations (10) tell us why the carbon is going (or coming from) major ocean regions and provide the basis for predicting long-term trends. Program elements (10) and (6) thus contribute significantly to the second part of Goal 2: to understand the mechanisms of oceanic uptake of CO₂.

Modeling and synthesis (11) provide large-scale checks on inferred oceanic and global fluxes, especially when exercised to provide global constraints using data from the global surface and airborne networks (elements (2) and (3)). Models allow tests of our understanding through simulations of past disturbances, such as major El Niño-Southern Oscillation (ENSO) events.

Goal 3: Program Elements 1, 4, 5, 7, 11

The program elements (5) (reconstruct historical land use) and (4) (expand global terrestrial carbon and land use inventories) are specifically designed to address Goal 3: to determine the impact of historical and current land

use. The expanded flux network (1), long-term terrestrial observations (7), and terrestrial process studies and manipulations (8) will provide integral checks and constraints on the interpretation of results from (4) and (5). Modeling and synthesis (11) will be the major tools bringing together the data and concepts developed by these program elements.

Goal 4: Program Element 11 (integrating elements 1-10)

The program element modeling and synthesis (11) represents the most comprehensive and integrating tool for Goal 4, projecting future atmospheric concentrations of CO₂. This goal is a major scientific undertaking, in which the models and analysis must be closely integrated with all other elements of the CCSP. To succeed, responsible agencies will need to develop a managerial framework with a unified vision of the program and with greatly enhanced mutual collaboration and strategic planning.

Goal 5: The Entire CCSP (all elements, integrated and coordinated)

Goal 5—developing the scientific basis for evaluating management decisions relating to CO₂ in many critical ways represents the culmination of the entire Carbon Cycle Science Plan. The ultimate measure of a successful carbon cycle research program will be found in its ability to provide practical answers to both scientific and societal questions.